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UTILITY PATENT APPLICATION TRANSMITTAL

(Only for new nonprovisional applications under 37 C.F.R. § 1.53(b))

Attorney Docket No.	28870
First Inventor or Application Identifier	Lambert Haner
Title	CONTROLLED RELUCTANCE AC INDUCTION MOTOR
Express Mail Label No.	EL355023653US

APPLICATION ELEMENTS
See MPEP chapter 600 concerning utility patent application contents.

ADDRESS TO: Assistant Commissioner for Patents
Box Patent Application
Washington, DC 20231

1. [X] * Fee Transmittal Form (e.g., PTO/SB/17)
(Submit an original and a duplicate for fee processing)

2. [X] Specification [Total Pages 25]
(preferred arrangement set forth below)
- Descriptive title of the Invention
- Cross References to Related Applications
- Statement Regarding Fed sponsored R & D
- Reference to Microfiche Appendix
- Background of the Invention
- Brief Summary of the Invention
- Brief Description of the Drawings (if filed)
- Detailed Description
- Claim(s)
- Abstract of the Disclosure

3. [X] Drawing(s) (35 U.S.C. 113) [Total Sheets 9]

4. Oath or Declaration [Total Pages 1]
   a. [X] Newly executed (original or copy)
   b. [ ] Copy from a prior application (37 C.F.R. § 1.63(d))
   (for continuation/divisional with Box 16 completed)
      i. [ ] DELETION OF INVENTOR(S)
      Signed statement attached deleting inventor(s) named in the prior application, see 37 C.F.R. §§ 1.63(d)(2) and 1.33(b).

NOTE FOR ITEMS 1 & 13: IN ORDER TO BE ENTITLED TO PAY SMALL ENTITY FEES, A SMALL ENTITY STATEMENT IS REQUIRED (37 C.F.R. § 1.27), EXCEPT IF ONE FILED IN A PRIOR APPLICATION IS RELIED UPON (37 C.F.R § 1.28).

5. [ ] Microfiche Computer Program (Appendix)

6. Nucleotide and/or Amino Acid Sequence Submission (if applicable, all necessary)
   a. [ ] Computer Readable Copy
   b. [ ] Paper Copy (identical to computer copy)
   c. [ ] Statement verifying identity of above copies

ACCOMPANYING APPLICATION PARTS

7. [ ] Assignment Papers (cover sheet & document(s))
8. [ ] 37 C.F.R.§3.73(b) Statement (when there is an assignee) [ ] Power of Attorney
9. [ ] English Translation Document (if applicable)
10. [ ] Information Disclosure Statement (IDS)/PTO-1449 [ ] Copies of IDS Citations
11. [ ] Preliminary Amendment
12. [X] Return Receipt Postcard (MPEP 503) (Should be specifically itemized)
13. [X] * Small Entity Statement(s) (PTO/SB/09-12) [ ] Statement filed in prior application, Status still proper and desired
14. [ ] Certified Copy of Priority Document(s) (if foreign priority is claimed)
15. [X] Other: Check in the amount of $ 423.00

16. If a CONTINUING APPLICATION, check appropriate box, and supply the requisite information below and in a preliminary amendment:
[ ] Continuation [ ] Divisional [ ] Continuation-in-part (CIP) of prior application No: _____/_____
Prior application information: Examiner _____ Group / Art Unit: _____
For CONTINUATION or DIVISIONAL APPS only: The entire disclosure of the prior application, from which an oath or declaration is supplied under Box 4b, is considered a part of the disclosure of the accompanying continuation or divisional application and is hereby incorporated by reference. The incorporation can only be relied upon when a portion has been inadvertently omitted from the submitted application parts.
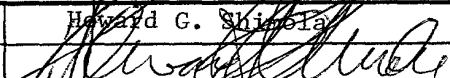
17. CORRESPONDENCE ADDRESS

[X] Customer Number or Bar Code Label   000,116   (Insert Customer No. or Attach bar code label here)   or [ ] Correspondence address below

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Signature		Date	Sept. 6, 2000

FEE TRANSMITTAL
for FY 2000

Patent fees are subject to annual revision.
Small Entity payments must be supported by a small entity statement,
otherwise large entity fees must be paid. See Forms PTO/SBI09-12.
See 37 C.F.R. §§ 1.27 and 1.28.

Complete if Known	
Application Number	
Filing Date	
First Named Inventor	Lambert Haner
Examiner Name	
Group / Art Unit	
Attorney Docket No.	28870

TOTAL AMOUNT OF PAYMENT	($) 423.00

METHOD OF PAYMENT (check one)

1. [XX] The Commissioner is hereby authorized to charge indicated fees and credit any overpayments to:

Deposit Account Number: **16-0820**

Deposit Account Name: **Pearne & Gordon LLP**

[X] Charge Any Additional Fee Required Under 37 CFR §§ 1.16 and 1.17

2. [X] **Payment Enclosed:**
[X] Check [ ] Money Order [ ] Other

FEE CALCULATION

1. BASIC FILING FEE

Large Entity Small Entity

Fee Code	Fee ($)	Fee Code	Fee ($)	Fee Description	Fee Paid
101	690	201	345	Utility filing fee	345
106	310	206	155	Design filing fee	
107	480	207	240	Plant filing fee	
108	690	208	345	Reissue filing fee	
114	150	214	75	Provisional filing fee	

SUBTOTAL (1) ($) 345

2. EXTRA CLAIM FEES

	Extra Claims		Fee from below	Fee Paid
Total Claims	[ ] -20** = [ ]	X	[ ]	= [ ]
Independent Claims	5 - 3** = 2	X	39	= 78
Multiple Dependent			[ ]	= [ ]

**or number previously paid, if greater; For Reissues, see below

Large Entity Small Entity

Fee Code	Fee ($)	Fee Code	Fee ($)	Fee Description
103	18	203	9	Claims in excess of 20
102	78	202	39	Independent claims in excess of 3
104	260	204	130	Multiple dependent claim, if not paid
109	78	209	39	** Reissue independent claims over original patent
110	18	210	9	** Reissue claims in excess of 20 and over original patent

SUBTOTAL (2) ($) 423

FEE CALCULATION (continued)

3. ADDITIONAL FEES

Large Entity Small Entity

Fee Code	Fee ($)	Fee Code	Fee ($)	Fee Description	Fee Paid
105	130	205	65	Surcharge - late filing fee or oath	
127	50	227	25	Surcharge - late provisional filing fee or cover sheet.	
139	130	139	130	Non-English specification	
147	2,520	147	2,520	For filing a request for reexamination	
112	920*	112	920*	Requesting publication of SIR prior to Examiner action	
113	1,840*	113	1,840*	Requesting publication of SIR after Examiner action	
115	110	215	55	Extension for reply within first month	
116	380	216	190	Extension for reply within second month	
117	870	217	435	Extension for reply within third month	
118	1,360	218	680	Extension for reply within fourth month	
128	1,850	228	925	Extension for reply within fifth month	
119	300	219	150	Notice of Appeal	
120	300	220	150	Filing a brief in support of an appeal	
121	260	221	130	Request for oral hearing	
138	1,510	138	1,510	Petition to institute a public use proceeding	
140	110	240	55	Petition to revive - unavoidable	
141	1,210	241	605	Petition to revive - unintentional	
142	1,210	242	605	Utility issue fee (or reissue)	
143	430	243	215	Design issue fee	
144	580	244	290	Plant issue fee	
122	130	122	130	Petitions to the Commissioner	
123	50	123	50	Petitions related to provisional applications	
126	240	126	240	Submission of Information Disclosure Stmt	
581	40	581	40	Recording each patent assignment per property (times number of properties)	
146	690	246	345	Filing a submission after final rejection (37 CFR § 1.129(a))	
149	690	249	345	For each additional invention to be examined (37 CFR § 1.129(b))	

Other fee (specify) _____

Other fee (specify) _____

Reduced by Basic Filing Fee Paid

SUBTOTAL (3) ($) 423.00

SUBMITTED BY			**Complete (if applicable)**	
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Signature			Date	Sept. 6, 2000

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Information on this form may become public. Credit card information should not be included on this form. Provide credit card information and authorization on PTO-2038.

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant: Lambert Haner

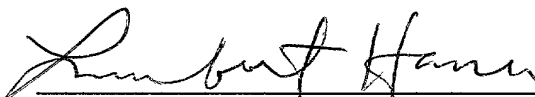Title: CONTROLLED RELUCTANCE AC INDUCTION MOTOR

Docket No: 28870

VERIFIED STATEMENT CLAIMING SMALL ENTITY STATUS

I hereby declare that I am an independent inventor for purposes of paying reduced fees to the Patent and Trademark Office with regard to the above-entitled invention, described in the specification filed herewith.

I have not assigned, granted, conveyed or licensed, and am under no obligation under contract or law to assign, grant, convey or license, any rights in the invention to any person or to any concern which would not qualify as a small business concern or a non-profit organization.

I acknowledge the duty to file, in this application, notification of any change in status resulting in loss of entitlement to small entity status prior to paying, or at the time of paying, the earliest of the issue fee or any maintenance fee due after the date on which status as a small entity is no longer appropriate.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this verified statement is directed.

_____

Lambert Haner
1975 Wynwood Drive
Rocky River, Ohio 44116

Date: _SEPT. 3, 2000_____

1   CONTROLLED RELUCTANCE AC INDUCTION MOTOR

2   The invention relates generally to the field of

3   electric motors and specifically to an AC motor with

4   improved performance characteristics.

5   PRIOR ART

6   Many types of electric motors are known to the

7   industry. Typically, these known motors have certain

8   desirable characteristics such as high starting torque,

9   variable speed and/or high power density. Often, however, a

10   motor with desirable characteristics for a given application

11   has certain disadvantages or deficiencies. These

12   undesirable characteristics often include relatively high

13   cost, electrical circuit complexity, radio frequency or

14   electromagnetic interference, energy inefficiency, limited

15   reliability and/or comparatively short service life.

16   SUMMARY OF THE INVENTION

17   The invention provides an AC power operated electric

18   motor that exhibits desirable torque/speed characteristics

19   when operated in an open loop condition and is effectively

20   speed and/or torque controlled with relatively simple and

21   economical electrical circuitry. The motor has a stator

22   with field windings that are energized with alternating

23   current and that are arranged to induce an AC current in a

24   conductive loop on a rotor or armature. In various

25   configurations of the motor, the field windings comprise at

26   least two coils angularly displaced from one another around

27   the rotor axis. The positions of the windings in some

28   configurations represent physically or mechanically distinct

29   phases.

1   The AC stator field is caused to move about the axis of
2   the rotor and the induced AC field in the conductive loop
3   produces a torque on the rotor causing it to rotate in
4   synchronization with the field rotation. The rotation of
5   the stator field is produced by switching or appropriately
6   modulating AC power to successive angularly displaced field
7   coils.

8   The motor can be arranged with 2, 4, 6 or even a
9   greater number of even poles and with as many field winding
10 phases as suitable for a particular application. Motor
11 torque, and therefore power, is multiplied in proportion to
12 the number of poles provided in the motor. The motor has
13 open loop speed/torque characteristics approaching the
14 desirable ideal of constant horsepower. These
15 characteristics include high starting torque and high speed
16 at low load.

17   Importantly, the motor lends itself to relatively
18 simple and energy efficient speed control and/or torque
19 control. A standard speed control over a 10:1 ratio is
20 readily achieved. Rated torque can be achieved at zero
21 speed with proper circuitry and therefore the speed range
22 can be from zero to the maximum rated speed. Some of the
23 additional advantages of the motor include low stall
24 current, operation on simple square wave power without
25 difficulty with harmonics, and increased power and/or torque
26 for a given physical size motor as compared to conventional
27 induction motors, for example.

28   BRIEF DESCRIPTION OF THE DRAWINGS
29   FIG. 1 is a schematic perspective view of a motor
30 illustrating principles of the invention;

1   FIG. 2 is a generalized graph illustrating the
2   relationship of torque versus rotor deflection angle for
3   motors constructed in accordance with the invention;
4   FIG. 3 is a schematic perspective view of a motor
5   constructed in accordance with the invention;
6   FIG. 4 is an electrical circuit diagram of a controller
7   for the motor of FIG. 3;
8   FIG. 5 is a generalized graph illustrating the
9   relationship of speed versus torque of a motor constructed
10 in accordance with the invention;
11 FIG. 6A is a diagram of square wave power available
12 from an inverter illustrated in FIG. 7;
13 FIG. 6B is a diagram of a modified square wave power
14 signal produced by the circuit of FIG. 7;
15 FIG. 7 is a circuit diagram for controlling the speed
16 of the motor of FIG. 3;
17 FIGS. 8A through 8D are diagrammatic representations of
18 signals developed in the circuit of FIG. 7;
19 FIG. 9 is a diagrammatic illustration of a system for
20 controlling the speed of a motor constructed in accordance
21 with the invention;
22 FIG. 10 is a schematic illustration of a motor arranged
23 for speed control by the control system of FIG. 9;
24 FIG. 11 is an alternative circuit for driving the motor
25 of FIG. 3;
26 FIG. 12 is a schematic representation of a motor of the
27 invention having field windings arranged in quadrature;
28 FIG. 13 is a circuit for driving the motor of FIG. 12;
29 FIG. 14 is a schematic perspective view of a four pole
30 three-phase motor constructed in accordance with the
31 invention; and

1 FIG. 15 is a diagrammatic illustration of the field
2 vectors of one of the windings of the motor of FIG. 14.

3 ## DESCRIPTION OF THE PREFERRED EMBODIMENTS

4 Referring now to FIG. 1, a motor 10 has a stator 11
5 with a field winding 12 and a rotor or armature 14 supported
6 by suitable bearing structure for rotation about an axis 16.
7 The winding 12 is arranged in two sections or portions 12a,
8 12b on diametrally opposite sides of the rotor 14. The
9 rotor 14 has a conductive loop 17 that has two diametrically
10 opposite portions 18 near the periphery of the rotor that
11 extend parallel to the rotor axis 16 and two end portions
12 19. A main body 21 of the rotor 14 can be constructed of
13 suitable magnetic silicon steel laminations in a manner
14 known in the art. The two loop portions 18 that extend
15 longitudinally of the rotor lie in a common plane that
16 passes through the rotor axis 16. For purposes of this
17 disclosure, the plane of the conductive loop 17 is taken as
18 the plane of the conductor portions 18. The conductive loop
19 17, which can be made of copper or aluminum, for example, is
20 electrically continuous; the end portions 19 shunt the
21 longitudinal portions 18. The stator 11 has its field
22 windings 12a, 12b wound about suitable magnetic material
23 such as a stack of magnetic silicon steel laminations 22a
24 and b.
25 When the field coil or winding 12 is energized with an
26 AC voltage, a magnetic field is created with a vector that
27 is parallel to an axis 23 extending between the windings
28 12a, b. With the field coil 12 thus energized with an AC
29 voltage, when the rotor 14 is displaced from the illustrated
30 solid line position through an angle ψ magnetic field
31 conditions urge the rotor 14 to return to the solid line

1   position where the plane of the conductive loop 17 is

2   aligned with the field axis 23. That is, the magnetic field

3   conditions urge the rotor 14 to the position where the angle

4   ψ is 0.

5   FIG. 2 is a generalized diagram of the relationship

6   between torque and angular displacement ψ. The diagram

7   shows that the torque tending to move the rotor 14 towards

8   the position of alignment with the axis 23 increases

9   proportionately with the displacement or angle ψ. Torque

10   reaches a maximum value at about 70°; at displacements

11   beyond this, the torque diminishes. At ψ equal to 90°, i.e.

12   when the plane of the conductive loop 17 is transverse to

13   the direction of the field vector of the winding 12, the

14   torque reduces to 0. This $\psi = 90°$ position can be called a

15   hard neutral while the position at ψ equal to 0 can be

16   called a soft neutral.

17   When the plane of the conductive loop 17 is turned from

18   alignment with the field vector of the stator 11, i.e. ψ not

19   equal to 0, the AC magnetic field produced by the winding 12

20   induces an AC current in the conductive loop 17. This rotor

21   current produces its own magnetic field which opposes the

22   stator field. The opposing field produced by the conductive

23   loop 17 increases the reluctance of the flux path of the

24   stator field. It can be shown that in an electromechanical

25   system, such as the motor 10 illustrated in FIG. 1, physical

26   laws work to reduce the reluctance in the system.

27   Consequently, the motor 10 behaves as discussed with the

28   rotor 14 being urged to a position where the plane of the

29   conductive loop 17 is aligned with the axes 23 and the

30   reluctance of the motor system being reduced.

31   The motor 10 of FIG. 1, as so far described, is not

32   practical as a general purpose rotating motor since it

1 cannot sustain continuous rotation of the rotor. However,
2 the motor's characteristics, as described, are helpful in
3 understanding the operation of other motors, constructed in
4 accordance with the invention, such as those described
5 hereinbelow.
6   FIG. 3 diagrammatically shows a motor 26 that applies
7 the foregoing principles in a two pole rotor 14, like that
8 described with reference to FIG. 1, but with a three phase
9 stator 28.   (The "two pole" designation pertains to the
10 rotor or armature and derives from north and south magnetic
11 poles produced by the conductive loop 17 when the loop is in
12 an AC magnetic field.)   The stator 28 typically includes a
13 body formed by a stack of laminations of suitable magnetic
14 silicon steel with internal axially oriented slots 30
15 distributed about the periphery of the rotor 14 as is
16 generally conventional in motor construction. A winding A
17 has turns wrapped axially around the rotor.   The turns
18 include longitudinal or axially oriented portions disposed
19 in the lamination slots 30 on diametrically opposite sides
20 of the rotor 14 and end portions circumferentially looped
21 around the axial projection of the rotor in a manner known
22 in the motor art.   The longitudinal portions of the turns of
23 the winding A are geometrically centered on a plane
24 represented at 31 that passes through the rotor axis 16.
25 For clarity, only the winding A is illustrated in FIG. 3 and
26 it will be understood that the other windings B and C are
27 similar in construction.   The planes of the windings A, B
28 and C are oriented at 120° relative to one another with
29 reference to the axis 14 of rotation of the rotor 14 and
30 pass through this axis so that adjacent portions of the
31 windings A, B and C are centered at 60° intervals.   The
32 winding A, when energized with AC power develops an AC

1 magnetic field vector 32 in a plane 33 perpendicular to the
2 plane 31 of the winding A. The other windings B, C,
3 similarly, produce AC magnetic field vectors perpendicular
4 to their respective planes. The windings A, B and C are
5 thus in a physical or mechanical phase relationship to one
6 another and are electrically isolated from one another. By
7 switching or modulating AC power sequentially to the
8 mechanically phased windings A, B and C, the rotor 14 will
9 be driven in rotation. As explained hereinabove, the rotor
10 14 will tend to align itself with the field vector of an
11 energized winding (or as discussed later the resultant field
12 vector of simultaneously energized field windings). When
13 the plane of the rotor conductive loop 17 approaches the
14 vector of the field from one energized winding, that winding
15 is de-energized while the adjacent winding in the direction
16 of rotor rotation is energized. By continuing this field
17 switching process, the rotor 14 is caused to rotate
18 continuously.
19   FIG. 4 illustrates an example of a circuit or
20 controller 36 suitable for driving the two pole, three
21 winding phase motor 26 of FIG. 3. The motor windings are
22 represented as A, B and C in the circuit of FIG. 4. In the
23 circuit, commercial power, e.g. 60 Hz, 110 volt, single
24 phase power is connected to lines 37, 38. This power is
25 converted to DC in a rectifier and voltage doubler circuit
26 comprising a pair of diodes 39, 41 and capacitors 42, 43.
27 Positive and negative voltages are developed on respective
28 lines or busses 46, 47.
29   Square wave AC power is supplied independently to each
30 winding A, B or C from paired power mosfet switches 51, 52
31 associated with each winding. One of the mosfet switches 51
32 supplies positive voltage while the other 52 supplies

1   negative voltage thereby producing an AC power signal. The

2   mosfet switches 51, 52 are driven by an associated

3   integrated circuit 53 (such as an IR 2104). These drivers

4   53 are powered by a suitable 12 volt DC source. Each driver

5   53 alternately operates the associated mosfets 51, 52 at a

6   frequency imposed by a frequency generator 54 (such as an

7   MCI 4046) signalling from its output (pin 4) to an input

8   (pin 2) of each driver 53. The frequency can be any

9   suitable frequency, preferably higher than commercial power

10   of 60 or 50 Hz. A typical frequency can be between 100 to

11   250 Hz but can be higher if design parameters require such

12   and appropriate materials are used.

13   A shaft encoder 56 (FIG. 3) of any suitable type and

14   preferably a non-contact type monitors the angular position

15   of the rotor 27 and, therefore, the plane of the conductive

16   loop 17. In the illustrated example of FIG. 3, the shaft

17   encoder 56 senses when a 60° arc on a drum rotating with the

18   rotor 14 associated with each winding A, B or C passes the

19   reference point of a non-rotating part 59 of the encoder

20   fixed relative to the stator 28. The drum 57 of the encoder

21   56 is divided into three channels, each channel

22   corresponding to one of the field windings A, B or C. The

23   encoder 56 signals the driver 53 of a particular field

24   winding A, B or C when an angular sector on the drum 57

25   associated with that particular winding is in proximity to

26   the non-rotating part 59 of the encoder. The encoder 56

27   maintains the signal to the appropriate driver 53 for a time

28   in which a field winding A, B or C develops a relatively

29   large torque on the rotor. This period will be, roughly

30   when the plane of the conductive loop 17 is between 75 and

31   15° out of alignment with the magnetic field vector of a

32   particular winding (i.e. $75° \geq \psi \geq 15°$.

1   The time period or, more properly, the angular duration

2   of energization of a particular field A, B or C can be set

3   by the geometry of the codes on the drum 57 of the encoder

4   56. The drum 57 may be encoded with arcs of detectable

5   material that have a dwell of 60°. This geometry allows

6   each winding, where there are three windings, to be

7   energized twice for each revolution of the rotor 14. While

8   a driver 53 is enabled (i.e. turned on) from a channel of

9   the encoder 56, the driver cycles the associated mosfet

10   switches 51, 52 on and off at the frequency produced by the

11   frequency generator 54. The mosfet switches 51, 52 thereby

12   apply a square wave AC power signal, at the frequency of the

13   generator 54, to the associated field winding A, B or C.

14   With the circuit of FIG. 4 when one of the windings A, B or

15   C is energized the other two windings are inactive.

16   The motor 26 of FIG. 3, driven by the open loop circuit

17   36 of FIG. 4 has a desirable speed torque curve

18   schematically illustrated in FIG. 5. It will be seen that

19   the motor 26 approaches a constant horsepower device.

20   Additionally, the motor 26 is characterized by relatively

21   high starting torque and is capable of relatively high speed

22   operation. A motor operating with the principles of the

23   motor 26 discussed in connection with FIGS. 3 and 4 can be

24   constructed with more field windings or field phases. The

25   windings, typically, can be evenly spaced around the stator

26   and suitable corresponding additional driver circuits and a

27   modified shaft encoder can be employed. Such a motor has

28   the advantage of less torque ripple than that of the

29   illustrated three phase motor 26.

30   The speed of the motor 26 and like motors can be

31   controlled by either controlling the power delivered to the

32   motor or by controlling the position of the shaft encoder

1 signals relative to the stator. Each method can have many
2 variations. Controlling the power to the motor may be
3 implemented very simply, but such control may not
4 necessarily produce the best efficiency over a wide speed
5 range. Controlling the relative positions of the encoder
6 signals may produce better efficiency, but may be more
7 complex in circuit implementation for certain applications.
8 In some applications, a combination of both methods may be
9 useful.
10 One way of controlling power for speed control is to
11 control the width of each 1/2 cycle of a voltage square wave
12 delivered to the motor. Full power of the square wave is
13 applied when each half cycle occupies the total time of one
14 half period as depicted in FIG. 6A. If the beginning of
15 each half cycle is delayed by some fraction of the half
16 period, as depicted in FIG. 6B, then the total amount of
17 power delivered to the motor is reduced. The motor is not
18 sensitive to waveform (does not need sine waves) so that
19 only the total energy per half cycle is significant. There
20 are many ways to implement this kind of control; a simple
21 version is shown in FIG. 7. This circuit is used in
22 conjunction with the circuit of FIG. 4. The frequency
23 generator 54 is redrawn here. As will be understood from
24 the following discussion, the circuit of FIG. 7 is
25 interposed in the lines from the encoder 56 to the drives 53
26 for the field windings A, B and C. The frequency signal
27 output of the frequency generator 54 is fed into pin 2 of IC
28 12 which is a four stage binary counter. Each stage divides
29 the frequency by 2. At pin 6 of IC 12 (the output of the
30 4th stage), the frequency is 1/16 of the input at pin 2.
31 The output frequency at pin 6 is fed into the driver stages
32 53 (at pin 2) of each power mosfet switch 51, 52 (FIG. 4)

1   that delivers power to a particular stator winding phase or

2   coil A, B or C. In this arrangement, the frequency

3   generator 54 is typically set to a frequency that is 16

4   times greater than what is used in the original circuit in

5   FIG. 4. The binary outputs from the other three stages are

6   connected to a summing resistor network 61 at the input of

7   an operational amplifier designated as IC 13 at pin 2. The

8   output signal at pin 1 of IC 13 will appear as a sawtooth

9   waveform and will be related to the square wave output on

10   pin 6 of IC 12 as shown in FIGS. 8A and 8B, respectively.

11   A speed command signal and a speed feedback signal

12   (e.g. derived from the shaft encoder) are summed

13   algebraically at pin 9 of IC 13 and the difference (speed

14   error signal) is produced at pin 8 of IC 13. At pin 14 of

15   IC 13 is the polarity inversion of the error signal. The

16   error signal is then compared with the sawtooth waveform by

17   the comparator circuit composed of pins 6, 5 and 7 of IC 13.

18   With reference to FIG. 8C, when the magnitude of the error

19   signal is below the sawtooth level, the output of pin 7 is

20   0; when the magnitude of the error signal is above the

21   sawtooth level, the output of pin 7 is positive (a logic

22   "1"). This output signal modulates the encoder signals that

23   feed into the power mosfet drivers 53. In essence, the

24   signal controls the turn on of each driver 53 at its pin 3.

25   This is accomplished by dual input "and" gates shown as IC

26   14 (MC 14081B). Signals from the encoder 56 feed into one

27   gate input and the signal from pin 7 of IC 13 feeds into the

28   second gate input. The output of each gate IC 14 then feeds

29   into the pin 3 of a respective driver 53. The result is a

30   power signal applied to the motor field windings A, B or C

31   as shown in FIG. 6D. As the speed error signal varies in

32   magnitude, the width of each half cycle will vary in

1 accordance.   Where the power is supplied as a sine wave,
2 such as from commercial power, a speed control circuit can
3 be arranged to eliminate the beginning of each half cycle,
4 typically in the manner an SCR is regularly used in like
5 service.
6   The second method that can be used for speed control is
7 to shift the encoder signals to different phase or winding
8 drivers in accordance to the magnitude of the speed error
9 signal.   FIG. 9 illustrates circuitry to accomplish this.
10 The select signal is derived from the speed control error
11 signal.
12   A motor 62 schematically shown in FIG. 10 has eight
13 field windings (a - h) and, accordingly, eight driver
14 circuits (corresponding to elements 53, 51 and 52 in FIG.
15 4).   The field windings a - h are like the windings A, B and
16 C in FIG. 3.   If a shaft position encoder or sensor 63 has
17 its signals directed to turn on the field coils which
18 produce the maximum torque, then the motor speed will
19 increase to the point where the load torque is equal to the
20 produced or developed motor torque.   To reduce the torque
21 and lower the speed, it is necessary to direct the signals
22 of the position encoder 63 to different field coils.   Speed
23 control can thus be obtained by switching the encoder
24 signals to different coils in response to the speed control
25 error signal.   The plane of the armature conductive loop 17
26 is shown in relationship to the field coil position labelled
27 a - h.   If coil a is energized, maximum torque is generated
28 in the counter-clockwise direction.   A magnetic field vector
29 64 of winding a is perpendicular to the plane of winding a.
30 If field coil b were energized, a lesser torque would be
31 created, and if field coil c were energized, an even lesser
32 torque would be developed.   By shifting the encoder

1 connection to energize different coils, the torque is

2 controlled. By using the speed error signal to determine

3 the switching, the motor speed can be regulated. The speed

4 error signal magnitude is compared to fixed signal voltage

5 levels that are stepped by fixed increments. When the speed

6 error exceeds each fixed level, a new connection arrangement

7 is made between the encoder and the field coils. For

8 example, with eight field coils, suppose that at the maximum

9 level, encoder output A controls coil a and encoder B

10 controls coil b, etc. Then, when the error signal drops to

11 the next level, a logic switching action takes place in a

12 multiplex gate 63 (FIG. 9) to connect encoder output A to

13 coil b, and encoder output B to coil c, encoder C to coil d,

14 etc. Then, when the error signal drops to the next level

15 down (third level), the logic switching action connects

16 encoder output A to coil c, and encoder output B to coil d,

17 encoder output C to coil e, etc. Thus, the control acts to

18 shift the position of the encoder signals in proportion to

19 the magnitude of the error signal. This action will then

20 increase or decrease torque and, accordingly, increase or

21 decrease speed.

22   FIG. 11 shows an alternative controller or circuit 70,

23 of simplified design, for operating the motor 26. Single

24 phase alternating current power such as 110 volt 60 Hz

25 commercial power is supplied to the windings A, B and C

26 through corresponding triacs 71 or other electrically

27 controllable switches. A frequency generator 73, (MCI 4046)

28 produces a series of pulses having a frequency that is

29 proportional to the voltage set by a potentiometer 72. The

30 pulses are input to a counter 74 such as a CMOS 4017. The

31 three outputs of the counter 74 are applied to sequentially

32 fire the triacs 71 through a buffer 76 such as a CMOS 4049

1   inverting buffer that feeds the opto isolator trigger to

2   each triac. The counter 74 assures that the windings or

3   phases A, B and C are triggered sequentially at a rate

4   corresponding to the frequency set by the voltage at the

5   potentiometer 72. The motor 26, when operated by the

6   circuit of FIG. 11, will run at a speed synchronous with the

7   rate that the field windings A, B and C are triggered. The

8   circuit 70 with the adjustable potentiometer 72 and variable

9   frequency of the generator 73 thus provides a simple method

10   of speed control for the motor 26. As this circuit 70 of

11   FIG. 11 suggests, the motor 26 and others constructed like

12   it in accordance with the invention can be operated directly

13   off a commercial single phase power supply such as, for

14   example, 120 volt 60Hz power where high speed operation is

15   not required. Conversely, this motor 26 and the circuit 70

16   can be supplied with a higher frequency power supply where

17   it is desired to operate the motor at higher speeds.

18   Innumerable other control systems and circuits are suitable

19   for operating a motor constructed in accordance with the

20   invention as will be apparent from an understanding of the

21   present disclosure.

22   A flux vector drive is also contemplated for the motor

23   of the invention. Referring to FIG. 12, a simple field

24   winding configuration for a two winding two pole motor 80 is

25   shown. Stator field or phase windings X, Y are physically

26   located in quadrature and labelled X and Y to correspond

27   with x and y axes. The windings X, Y create magnetic flux

28   vectors along the corresponding x and y axes. Currents

29   flowing through both sets of windings X and Y create a

30   magnetic field flux vector 81 which is the vector sum of the

31   individual magnetic flux vectors created by the currents in

32   the separate windings X, Y. A vector angle θ of the vector

1 varies with respect to the X axis depending on respective

2 magnitudes of the currents in windings X, Y.

3   The magnitudes of the AC currents in the windings X, Y

4 are:

5         $I_X = \cos\theta \, \sin 2\pi f_c t$; and

6         $I_Y = \sin\theta \, \sin 2\pi f_c t$;

7 where f_c is the frequency of the current supplied, such as

8 60 Hz. The field flux vector 81 represents an alternating

9 magnetic field with the frequency f_c. The field flux vector

10 81 can be positioned at any angle θ by varying the currents

11 in the field windings X, Y according to the following

12 relationship:

13
$$\theta = \sin^{-1}\left(\frac{I_Y}{\sqrt{I_x{}^2 + I_Y{}^2}} \right)$$
14

15

16 The motor 80 has a rotor 14 like that described in

17 connection with FIG. 1; the plane of the conductive loop 17

18 is displaced from the X axis by a rotor angle ϕ. The rotor

19 14 rotates synchronously at the speed that the field vector

20 81 is rotated. As discussed below, the field windings can

21 be supplied with modulated AC currents from power amplifiers

22 operated by a signal processor to appropriately rotate the

23 magnetic field vector 81.

24   By creating and controlling a difference between the

25 field flux vector angle θ and the rotor angle ϕ, the torque

26 output of the motor 80 can be controlled. That is, the

27 torque is controlled by controlling the relative positions

28 of the field flux vector and the plane of the conductive

29 loop 17 on the rotor 14. As discussed previously with

30 reference to FIG. 2, torque is developed when the rotor or

31 armature 14 is located where there is an angular deflection

32 ψ between the plane of the conductive loop 17 and the flux

1 vector between the winding portions 12a, b; this torque

2 varies with the magnitude of the angle ψ. Similarly, in

3 FIG. 12, the torque varies with the difference between the

4 flux vector angle θ and the rotor angle ϕ. Note the

5 relationship $\psi = \theta - \phi$.

6 As previously discussed, the vector angle θ is varied

7 by varying the current amplitudes in the field windings X,

8 Y. Since the currents are AC, the field currents will be

9 suppressed carrier amplitude modulated sine waves that can

10 be represented as:

11 $I_X = \cos(\omega_R t \pm \psi) \sin 2\pi f_c t$; and

12 $I_Y = \sin(\omega_R t \pm \psi) \sin 2\pi f_c t$;

13 where ω_R is the rotational speed of the rotor 14. The

14 angular deflection ψ with respect to the field flux vector

15 is determined by the respective field currents I_X, I_Y and

16 the angular velocity ω_R:

17
18 $$\pm\psi = \sin^{-1}\left(\frac{I_Y}{\sqrt{I_X^2 + I_Y^2}}\right) - \omega_R t$$
19

20 Referencing FIG. 2, the deflection angle ψ is varied to

21 achieve the desired torque characteristics by varying the

22 currents I_X, I_Y. The rotor position ϕ is sensed, for

23 example, by a transducer or electrical parameters. Rotor

24 position information is used to control the flux vector

25 position θ to maintain the desired deflection ψ and,

26 therefore, the motor torque.

27 A flux vector control circuit 85 that applies the

28 foregoing principles and relationships of field current,

29 field vector and rotor angle for torque control is shown in

30 FIG. 13. The control 85 includes a signal processor 86 with

31 two outputs for generating the currents I_X, I_Y. The

32 currents are fed through respective power amplifiers 87 to

1   the field windings X, Y. Frequency F_c is set by a suitable

2   frequency input. A rotor position sensor 89, such as a

3   numerical shaft position sensor, provides rotor position

4   information data to the signal processor 86. A torque

5   command input, corresponding to a deflection angle ψ is

6   provided to the signal processor to control torque. The

7   signal processor 86 in accordance with the foregoing

8   formulas generates the currents I_X, I_Y as functions of the

9   frequency F_c, rotor position ϕ (which indicates rotor speed

10 ω_R), and torque command deflection angle ψ to control the

11 torque characteristics of the motor 80. The speed of the

12 motor is controlled according to the rate ω at which the

13 carrier signal is modulated, which can be selected by a

14 speed input. The rotor position sensor can be connected to

15 provide speed or position feedback, diagrammatically

16 represented at 88, through a torque control 84 to control

17 the torque command angle setting ψ.

18   A motor constructed in accordance with the invention

19 can be made with four poles as schematically shown in FIG.

20 14. The motor 90 can develop twice the torque of a

21 similarly sized two pole motor such as the motor 26 in FIG.

22 3. The illustrated motor 90 has three field winding phases

23 designated Phase A, Phase B and Phase C. Each Phase A, B

24 and C has f our coils 91, 92, 93, and 94. Each of these

25 coils has a pair of spaced axially extending portions 96 and

26 a pair of end turn portions 97, one at each end of a stator

27 typically of suitable laminations represented by the

28 circular line 98. The coils 91, 92, 93 and 94 are connected

29 in series with alternate coils wound in a clockwise

30 direction and intervening coils wound in counter-clockwise

31 direction. Alternatively, the coils 91 - 94 can be

32 connected in parallel. For clarity, the coils 91 - 94 of

1 only one phase (A) is shown, it being understood that the

2 other phases B and C are identical. A rotor 99 of the motor

3 90 has four conductive wires or rods 100 equally spaced

4 around the circumference of the rotor 99 and extending

5 longitudinally of the rotor. The conductors 100 are

6 interconnected or shunted by end wires or conductors 101 at

7 each end of each conductor 100. The longitudinal conductors

8 100, like the conductors 17 of the rotor 14 of FIG. 3, are

9 parallel with the axis of rotation of the rotor 99 on a

10 shaft 95. The rotor 99 and stator 98 typically include

11 bodies formed of silicon steel laminations as previously

12 described. The windings of Phases A, B and C can be

13 energized by a circuit like that shown in FIGS. 4 or 11.

14 Motors having a greater even number of poles such as 6, 8 or

15 more, can be constructed similarly to the four pole motor of

16 FIG. 14 and such motors will have a proportionately higher

17 torque capacity.

18   As will be understood from the foregoing disclosure,

19 the motor of the invention can take various forms and can be

20 powered by innumerable electrical circuit arrangements, both

21 open and closed loop. Switches for the field windings can

22 include triacs, transistors, silicon controlled rectifiers

23 (SCR's) and magnetic amplifiers, for example. The rotor,

24 rather than having a conductive loop to present a variable

25 reluctance to the stator field, can be formed with a

26 diametrically disposed air gap or a conductive plate in the

27 plane otherwise occupied by the conductive rotor loop. The

28 rotor can be disposed around, rather than in, the stator.

29 The conductive loop or loops on the rotor can be skewed in a

30 helical or like sense to reduce torque ripple. The number

31 of field windings and related electronic switches, also, can

32 be increased to decrease torque ripple. Some of the turns

1 of a particular winding can share the same stator lamination

2 slot or angular position as some of the winding turns of an

3 adjacent winding.

4   The motor can be supplied with a shaft encoder and

5 appropriate circuitry for operation as a stepping motor and

6 is especially suitable for large size stepping motors. A

7 desired angular resolution for a stepping motor application

8 can be achieved by providing a suitable number of field

9 windings. As previously discussed herein, the rotor will

10 seek to align the plane of the conductive loop, or

11 equivalent structure, to the magnetic field vector of a

12 particular winding that is energized. The motor is

13 reversible simply by reversing the sequence that the field

14 windings are energized by the related circuitry.

15   A circuit powering the field windings of the motor can

16 energize more than one field winding at a time to reduce

17 torque ripple and/or the circuit can be arranged to modulate

18 power to the windings rather than simply turning them on and

19 off. Field windings on the stator can have various

20 configurations besides those illustrated in FIGS. 1, 3 and

21 14, it being important that the winding arrangement be

22 capable of producing an AC magnetic field in the space of

23 the rotor that moves around the axis of the rotor.

24   While the invention has been shown and described with

25 respect to particular embodiments thereof, this is for the

26 purpose of illustration rather than limitation, and other

27 variations and modifications of the specific embodiments

28 herein shown and described will be apparent to those skilled

29 in the art all within the intended spirit and scope of the

30 invention. Accordingly, the patent is not to be limited in

31 scope and effect to the specific embodiments herein shown

32 and described nor in any other way that is inconsistent with

1   the extent to which the progress in the art has been
2   advanced by the invention.

WHAT IS CLAIMED IS:

1   1.   An AC electric motor comprising a stator and a
2   rotor journalled for rotation about an axis relative to the
3   stator, the rotor having an electrically continuous
4   conductive loop, the loop having longitudinal portions
5   spaced from and generally parallel to the axis and shunt
6   portions extending between the ends of the longitudinal
7   portions, the stator having at least two separate windings
8   angularly displaced from one another about the axis of the
9   rotor, an electrical circuit for selectively energizing and
10   de-energizing the field windings with separate AC currents
11   to develop an AC magnetic field vector that moves around the
12   rotor axis, the field windings and conductive loop being
13   arranged so that the AC magnetic field vector induces an AC
14   current in the conductive loop and the reluctance of the
15   loop operates to develop torque on the rotor that tends to
16   cause it to rotate in synchronization with the movement of
17   the magnetic field vector.

1   2.   An electric motor as set forth in claim 1, wherein
2   the field windings comprise 3 or more coils distributed
3   about the rotor axis.

1   3.   An AC motor as set forth in claim 2, including a
2   circuit arranged to energize successive ones of said
3   windings in a constant angular direction around said rotor
4   axis while de-energizing angularly preceding ones of said
5   windings.

1   4.   An AC motor as set forth in claim 3, wherein said
2   circuit provides an AC square wave for powering said
3   windings.

1   5.   An AC motor as set forth in claim 3, wherein said
2   circuit is arranged to provide an AC voltage waveform and to
3   change the characteristics of said waveform to vary the
4   speed or torque of the motor.

1   6.   An AC motor as set forth in claim 1, wherein said
2   field windings comprise first and second windings, said
3   second winding being oriented to produce a magnetic field
4   vector at right angles to the magnetic field vector of the
5   first winding, said electric circuit being arranged to
6   modulate the currents in said windings to produce a
7   resultant magnetic field vector that is positioned about the
8   axis of the rotor.

1   7.   An AC motor as set forth in claim 1, wherein said
2   circuit is arranged to control the position of the magnetic
3   field vector in relation to the rotor to regulate speed or
4   torque.

1   8.   An AC motor as set forth in claim 1, wherein the
2   rotor has a plurality of pairs of conductive loops and the
3   windings are arranged to produce magnetic field vectors that
4   pass through the space of the rotor in chordal-like zones.

1   9.   An electric motor comprising a stator and a rotor,
2   field windings on the stator for producing an AC magnetic
3   field with a vector at successive angular positions around
4   the axis of rotation of the motor when the windings are

5   successively energized with single phase AC power, the rotor

6   having a construction by which it increases the reluctance

7   in the magnetic field when it has an angular orientation out

8   of alignment with the magnetic field vector compared to its

9   reluctance when it is aligned with the magnetic field vector

10   whereby the rotor seeks to rotate in synchronization with

11   the magnetic field vector produced by the field windings.

1   10. A controller circuit for an AC motor comprising a

2   plurality of switches and/or amplifiers that generate

3   separate power signals at respective outputs, each power

4   signal having an AC frequency common with the other signals,

5   the signals varying in amplitude in a cyclic manner

6   corresponding to the speed of rotation of the rotor of the

7   motor.

1   11. A method of operating an electric motor having a

2   stator and a rotor which includes causing an AC magnetic

3   field vector to be displaced around the axis of the rotor by

4   sequentially energizing field windings on the stator and

5   providing the rotor with a construction that has a variable

6   reluctance in the magnetic field whereby the rotor turns

7   with the movement of the magnetic field vector because its

8   reluctance in the magnetic field decreases when it is

9   aligned in a particular orientation with the magnetic field

10   vector.

1   12. A method of converting electrical energy to

2   mechanical energy comprising the steps of assembling a rotor

3   and stator in a manner enabling the rotor to rotate about an

4   axis relative to the stator, providing field windings on the

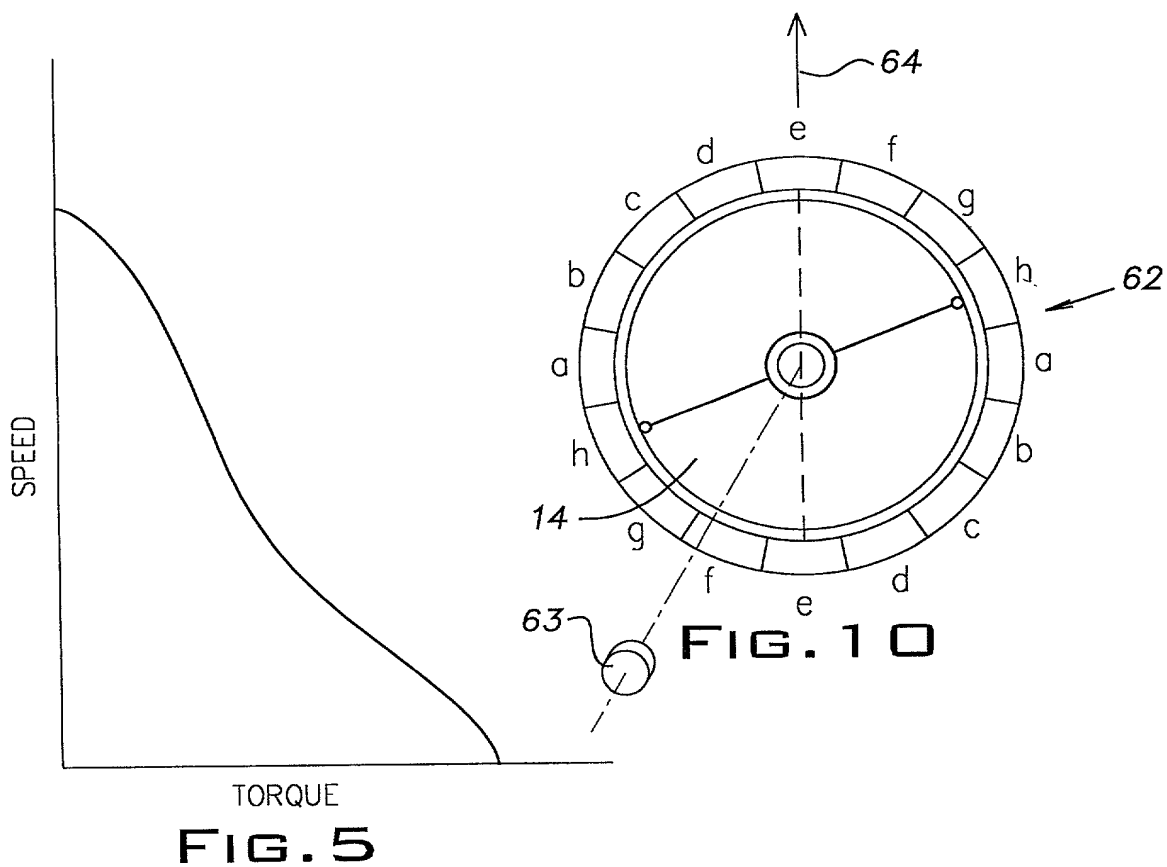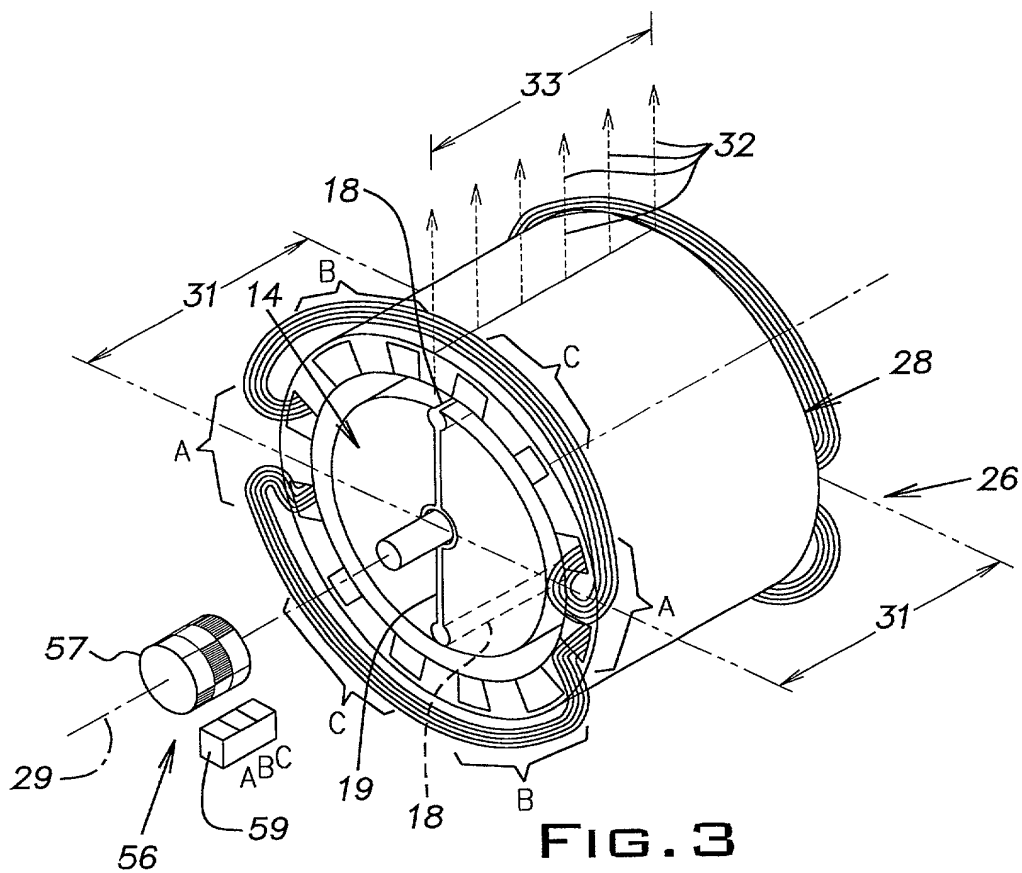5   stator capable of producing an AC magnetic field vector in

6 the rotor, providing the rotor with a reluctance that varies
7 with its angular orientation relative to the AC magnetic
8 field vector produced by field windings, energizing the
9 field windings with AC current in a manner that causes an AC
10 magnetic field vector to move around the axis of the rotor
11 and thereby cause the rotor to rotate in synchronization
12 with the movement of the AC magnetic field vector around the
13 axis.

1 13. A method as set forth in claim 12, wherein the
2 rotor is constructed with at least one conductive loop that
3 includes diametrically opposed axially extending portions
4 adjacent the periphery of the rotor so that the AC magnetic
5 field vector is able to induce an AC current in the loop
6 when a plane defined by said axially extending portions is
7 at an angle relative to the AC magnetic field vector.

1 <u>CONTROLLED RELUCTANCE AC INDUCTION MOTOR</u>

2 <u>ABSTRACT OF THE DISCLOSURE</u>

3 An electric motor operated by AC current, that includes

4 a stator and a rotor supported for rotation about an axis

5 relative to the stator. The stator is provided with field

6 windings angularly distributed about the rotor axis and

7 capable of producing a magnetic field vector in the space of

8 the rotor. Circuitry delivers AC current to the windings in

9 a manner that produces an AC magnetic field vector that

10 moves around the axis of the rotor. The rotor has a

11 construction, such as an axially extending conductive loop,

12 that changes its reluctance in the AC magnetic field

13 depending on its orientation to the AC magnetic field vector

14 whereby the rotor is caused to rotate in synchronization

15 with the movement of the AC magnetic field vector.

Fig.1

Fig.2

FIG.3

FIG.10

SPEED

TORQUE

FIG.5

FIG.4
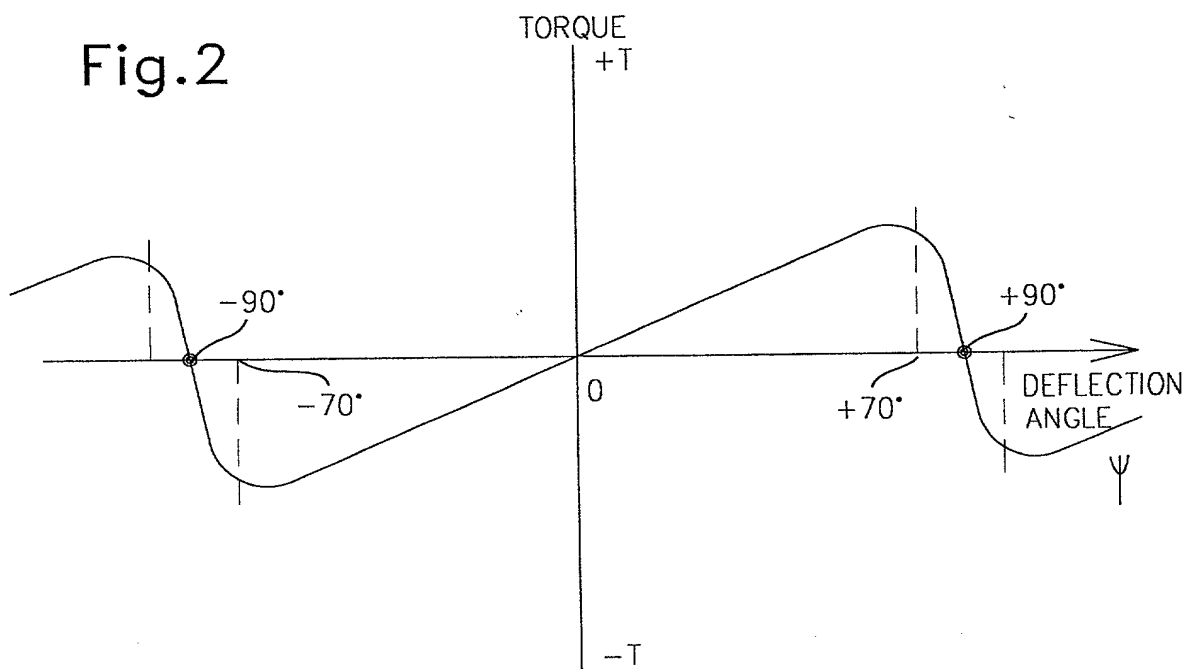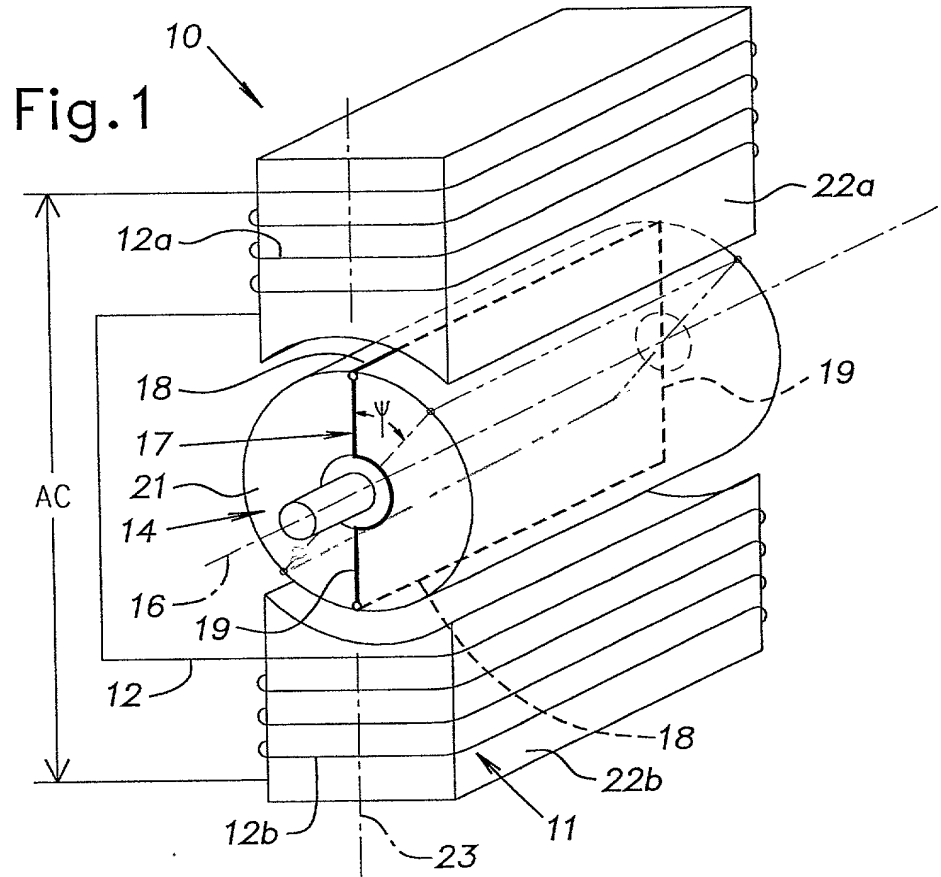
INVERTER SQUARE WAVE
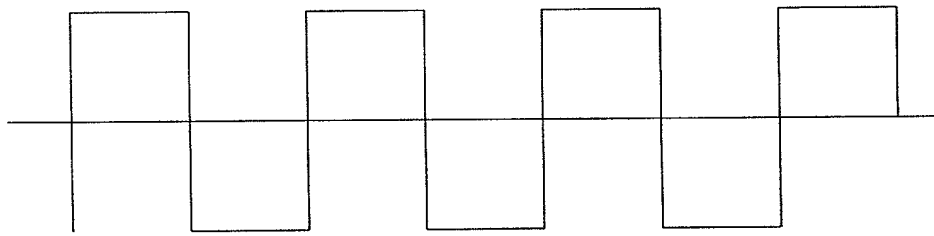
FIG.6A

CYCLE WIDTH CONTROL OF POWER
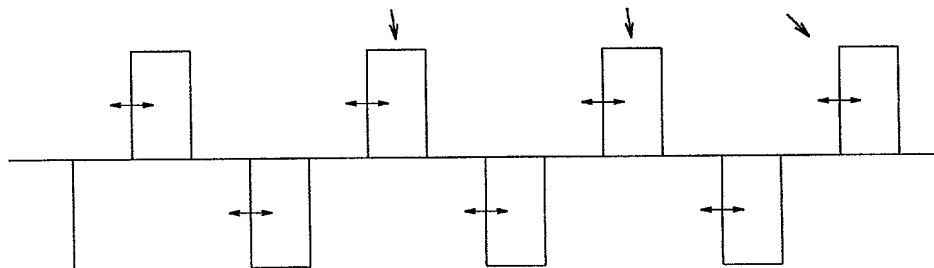
FIG.6B

SHAFT SENSOR
SIGNALS
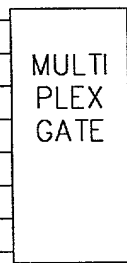
FIG.9

FROM ENCODER OUTPUT

A

B

C

TO PIN #3 OF 53 PHASE A

TO PIN #3 OF 53 PHASE B

TO PIN #3 OF 53 PHASE C

IR2104

IR2104

IR2104

+12
14

3

1
2

7

4

5
6

10

8
9

IC 14
4071

IC13
LM324

6

5

7

Vc

+12
0

OUTPUT WAVEFORMS
AT PIN #7
WIDTH VARIES
TO CONTROL SPEED

1
2
3

-12
+12

50K

SQUARE WAVE OUTPUT

+12

IC1
4046
VOLTAGE
TO
FREQUENCY
CONVERTER

16
9

11
12
6
7

R1
R2

3 5 8 14

2

IC12
MC14520
FOUR
STAGE
BINARY
COUNTER

6
3
4
5

400K
200K
100K

16

2
7
9
10
15
8

+12

14

13
12

Vc

8
9
10

+12 SPEED COMMAND POT

10K

-V

SPEED FEEDBACK
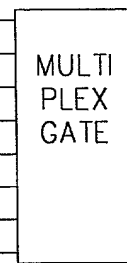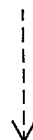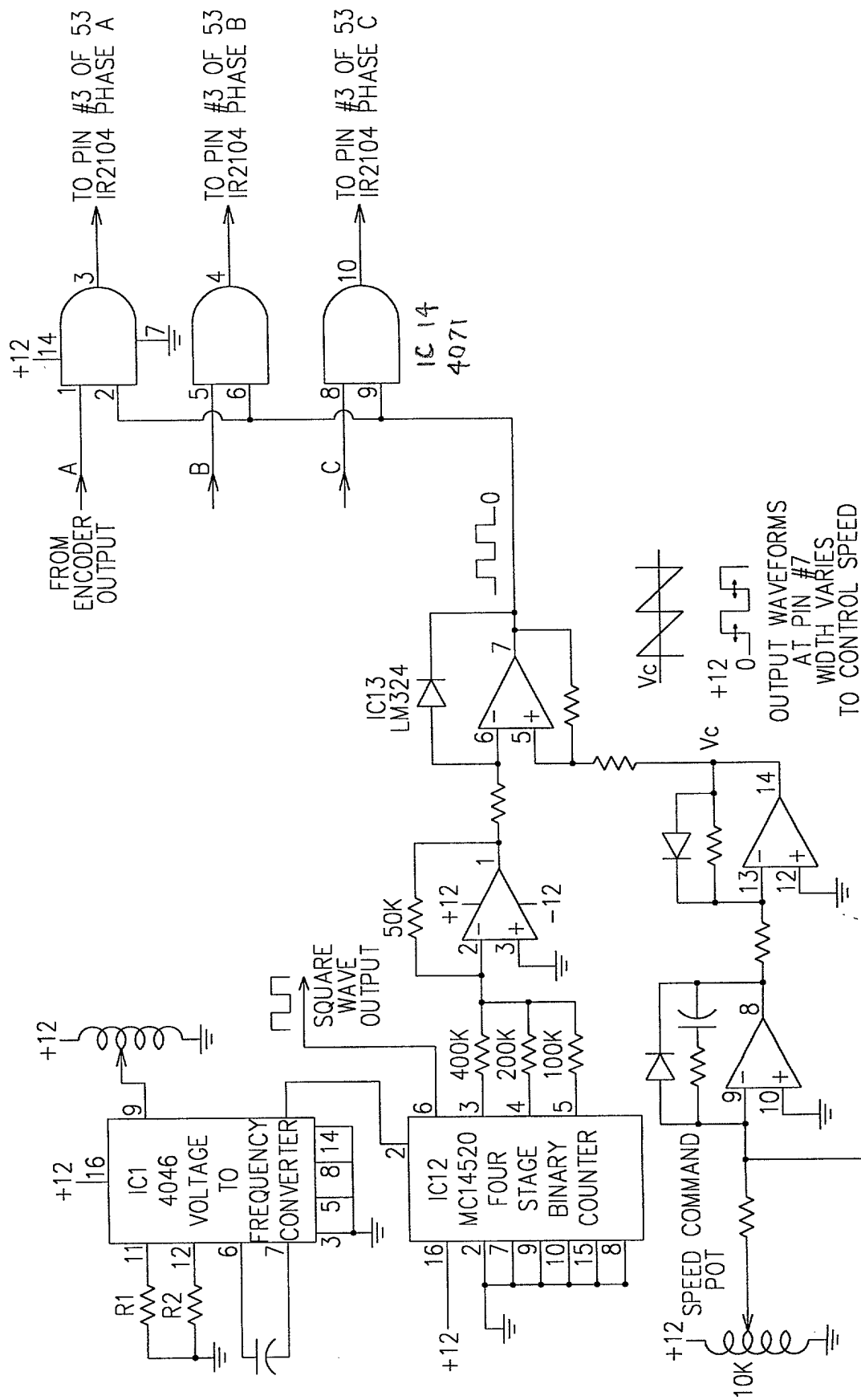
SPEED CONTROL METHOD BY VARYING THE
CYCLE WIDTH OF THE POWER FREQUENCY

FIG.7

SAWTOOTH WAVEFORM AT PIN#1 IC13
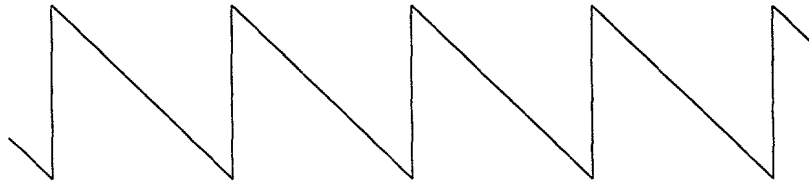
FIG.8A

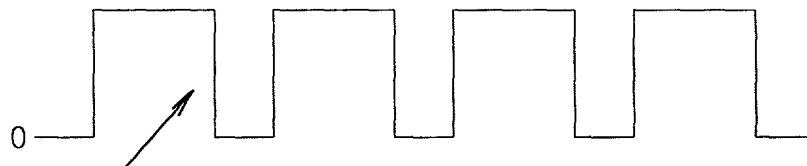SQUARE WAVE OUTPUT PIN#6 IC12
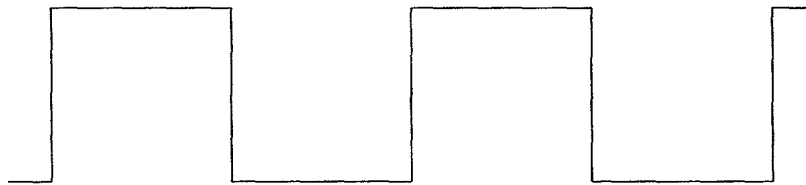
FIG.8B
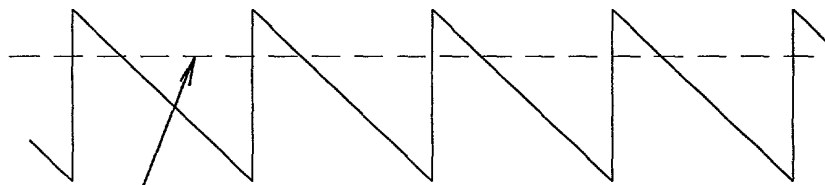
SPEED ERROR
SIGNAL LEVEL

FIG.8C

0

OUTPUT AT
PIN#7 IC13
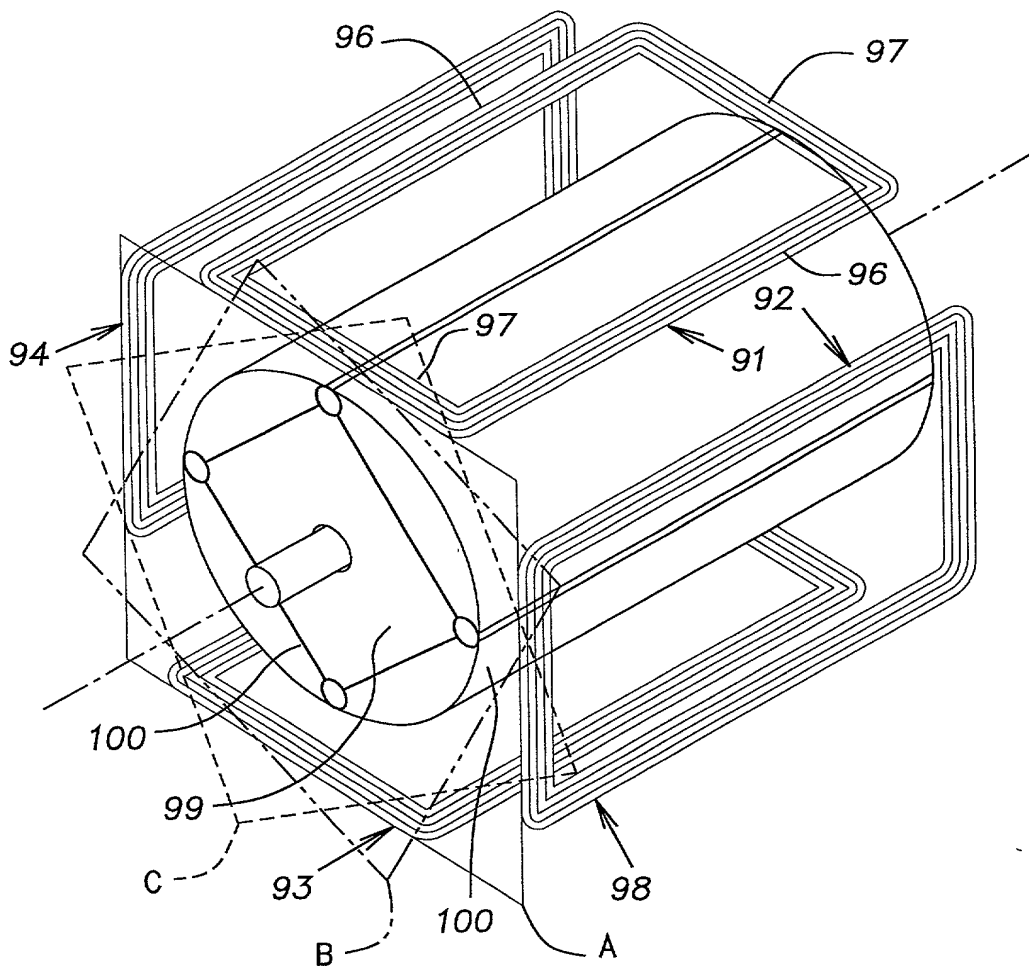
FIG.8D

Fig.11

Fig.12

Fig.13
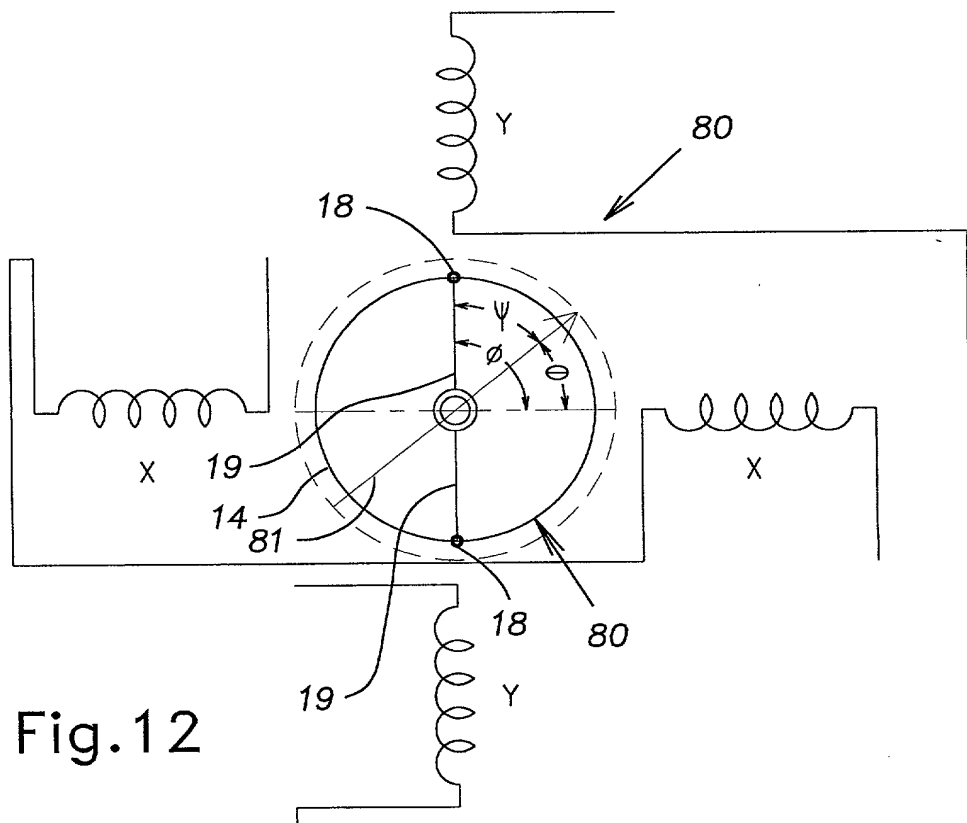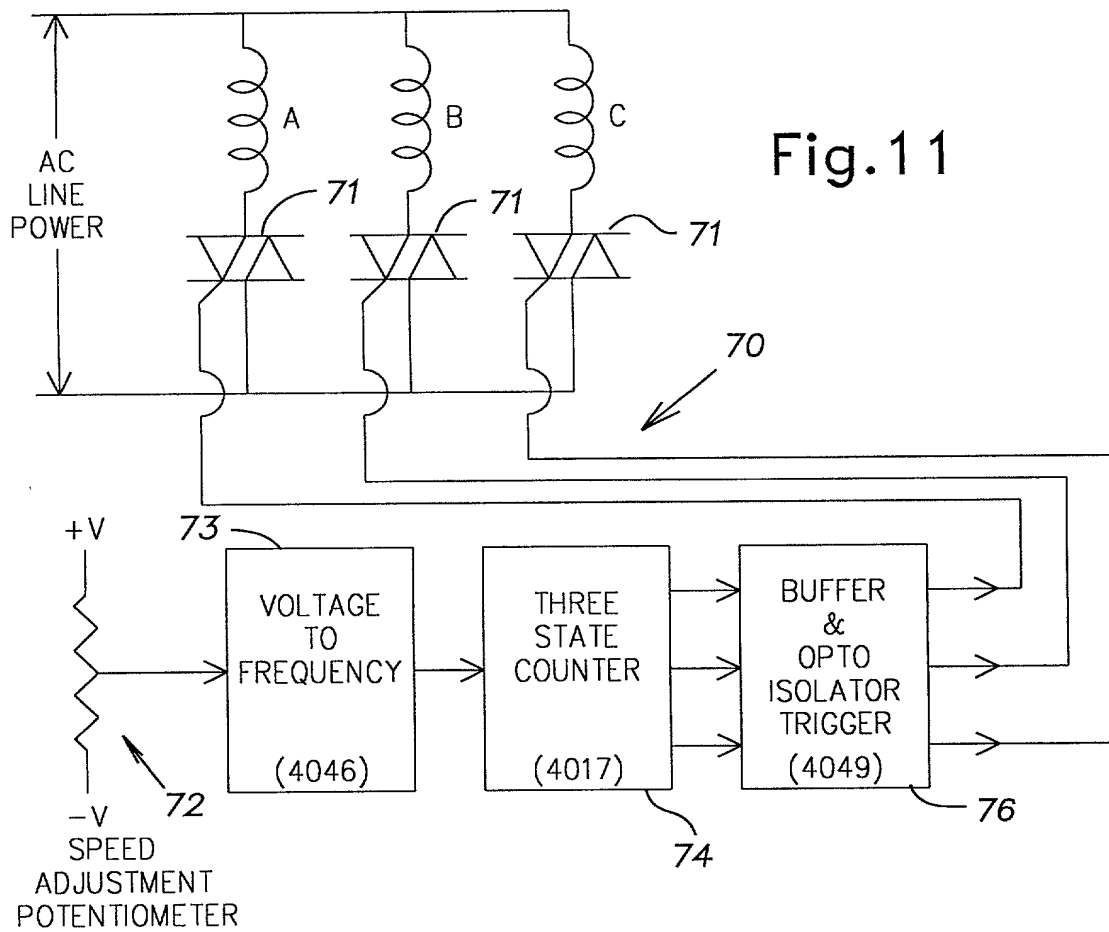
FIG. 14

DECLARATION AND POWER OF ATTORNEY
(Sole Inventor)

I, Lambert Haner, hereby declare that I am a citizen of the United States of America and a resident of 1975 Wynwood Drive, Rocky River, Ohio 44116; that I have reviewed and understand the content of the attached specification, including the claims (Pearne & Gordon LLP Docket No. 28870), and I believe that I am the original, first, and sole inventor of the subject matter which is claimed therein and for which a patent is sought on the invention or discovery entitled

CONTROLLED RELUCTANCE AC INDUCTION MOTOR

and that I acknowledge my duty to disclose information of which I am aware which is material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56.

I hereby designate the following as my mailing address and telephone number:

Pearne & Gordon LLP
526 Superior Avenue, East
Suite 1200
Cleveland, Ohio 44114-1484
(216) 579-1700

and appoint each of the following as my attorneys with full power of substitution and revocation, to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith:

Charles B. Gordon, Reg. No. 16923	Jeffrey J. Sopko, Reg. No. 27676
Richard H. Dickinson, Jr., Reg. No. 18622	John P. Murtaugh, Reg. No. 34226
Thomas P. Schiller, Reg. No. 20677	James M. Moore, Reg. No. 32923
David B. Deioma, Reg. No. 22841	David E. Spaw, Reg. No. 34732
Joseph J. Corso, Reg. No. 25845	Michael W. Garvey, Reg. No. 35878
Howard G. Shimola, Reg. No. 26232	Aaron A. Fishman, Reg. No. 44682

I further declare that all statements made herein of my own knowledge are true and that all statements made herein on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Lambert Haner   Date _SEPT. 3, 2000_

Lambert Haner

Post Office Address: 1975 Wynwood Drive, Rocky River, Ohio 44116

PGM&G PT101